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Auditory Processing of Complex Sounds Across Frequency Channels (AFOSR-89-0335)

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ANNUAL TECHNICAL REPORT (May 1, 1990 to May 1, 1991)

AFOSR-89-0335

Psychophysics-Auditory Object Perception William A. Yost and Stanley Sh ft

Our work has centered on the discovery of the MDI or Modulation Detection Interference phenomenon, in which the modulation properties of tonal components in multi-tone complexes can not be processed when all the tones are modulated at the same low modulation rate as well as when the tones are not modulated or when the modulation rates differ for different components. We have argued that MDI results from the fact that the coherent modulation of all of the components fuse them into a single auditory image, and since coherent modulation was the basis of the perceptual fusion, temporal modulation for any one tone is not easily processed. We recently tested a corollary to this assumption. That is, when tonal complexes are fused into an auditory image based on coherent temporal modulation and MDI occurs, can subjects still process other attributes of the tones (e.g. changes in frequency and intensity) since these other attributes were not the basis for the tones being fused into a single image (coherent modulation was the "fusing" attribute)? ~~We~~ showed that although the detection of modulation was severely interfered with when two tones are coherently modulated, neither the discrimination of a change in frequency or a change in intensity was disrupted for the coherently modulated tones. This, confirmed ~~our~~ hypothesis and suggests a type of rule for auditory image formation: If one physical attribute of sound is used to form an auditory image from different spectral components, then the processing of that attribute for any of the individual components of the image, but not the processing of other attributes, will be impaired.

In addition to this empirical work, ~~we spent~~ ~~last year~~ develop~~ing~~ the concept of auditory image perception and analysis as a major aspect of auditory perception and the processing of complex sounds by the auditory system. This work was presented at the Evolution of Hearing Meetings, the Midwinter Meetings of the Association for Research in Otolaryngology, and will appear this summer as a major review article in the Journal of Hearing Research: "Auditory Image Perception and Analysis: The Basis of Hearing."

Papers:

Sheft, S. and Yost, W.A. (1990). Temporal integration in amplitude modulation detection, Journal of the Acoustical Society of America 88, 796-805.

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Physics.

Yost, William A. and Stanley Sheft (1990), Modulation detection interference for discriminating a change in the depth of amplitude modulation, Journal of the Acoustical Society of America 88, S146.

In Manuscript or Submitted:

Yost, William A., Tonal Temporal Modulation Transfer Functions, Journal of the Acoustical Society of America, in manuscript.

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Yost, William A. and Raymond Dye, Properties of Sound Localization by Humans, in Neurobiology of Hearing: The Central Nervous System, R. Altschuler, D. Hoffman, R. Bobbin, and B. Clopton (eds), Raven Press, 1991.

Yost, William A. Frequency and Intensity Discrimination in a Modulation Detection Inference (MDI) Paradigm, in Auditory Physiology and Perception (Y. Cazals, L. Demany, K. Horner, eds), in press.

Yost, William A. The Story of the Evolution of Hearing: Auditory Image Perception and Temporal Modulation, in The Biological Evolution of Hearing (A. Popper, D. Webster, R.R. Fay, eds), Springer Verlag, in press

Presentations:

Yost, William A. Locating Sound in Three-Dimensions over Headphones, Colorado Workshop on Otology and Audiology, Colorado, 1991.

Yost, William A. Frequency and Intensity Discrimination in a Modulation Detection Inference (MDI) Paradigm, International Symposium on Auditory Physiology and Perception, Carcans, France, 1991.

Yost, William A. Auditory Image Analysis: The Basis of Hearing, Association for Research in Otolaryngology, St. Petersburg Beach, 1991.

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Psychophysics--Envelope Processing by the Binaural Auditory System Raymond H. Dye, Jr.

A study was undertaken this past year that sought to gain insight into the processes by which multiple high-frequency carriers are lateralized when they are amplitude modulated. Of special interest were potential differences in performance when the target carrier (the component that was sinusoidally amplitude-modulated such that the envelope presented to the left ear led the one that was presented to the right ear) and neighboring carriers were modulated at the same (200 Hz) versus when the distractors were modulated at a rate different from that of the carrier.

The interaurally delayed component ("target") was a 3000-Hz-carrier, 100% amplitude-modulated by a 200-Hz sinusoid. The distractors were additional carriers that were 100% amplitude-modulated at 25, 50, 100, 200, or 400 Hz. The number of distractors was fixed at two, and the spacing between the distractors and the target (Δf) was varied from 500 to 1500 Hz. For comparison, threshold delays were measured for amplitude modulated 3000-Hz targets presented in isolation. The signals were 200 ms in duration, gated with 10 ms rise-decay times, with the distractors and the target gated simultaneously at the two ears. A two-interval task was used such that the first interval always presented a diotic 3000-Hz carrier modulated at 200 Hz and the second interval presented all three carriers. On half of the trials, the modulated 3000-Hz target was interaurally delayed (to the right channel) during the second interval; otherwise it was diotic (as were the distractors).

In addition to assessing the performance of subjects, they were interrogated regarding the listening strategies employed on a particular run of trials. The subjects' reports indicate that (1) targets and distractors that are modulated at the same frequency tend to be perceptually fused such that the entire complex sounds shifted during dichotic presentations, even though only the 3000-Hz carrier is delayed, (2) the detection of delays presented when the distractors and targets are modulated at different rates is accomplished by "hearing out" the target when it is delayed during the second interval as long as the frequency separation between the target and distractors is at least 1000 Hz, (3) the target and distractors are often perceptually fused, forming single intracranial events, when the target and distractors are separated by only 500 Hz even though the modulation frequencies of the target and distractors might differ (25 Hz vs. 200 Hz). In many of these cases under (3), the task can be accomplished <u>either</u> by hearing out the delayed component or fusing the complex.

Objective psychophysical measures of performance show that sensitivity is quite good for conditions in which the distractors and target are spectrally remote <u>and</u> modulated at different rates, with performance approaching what is found for targets presented in isolation. When the target and distractors are modulated at the same rate, significant binaural interference is observed regardless of the frequency separation between targets and distractors; the presence of distractors elevates thresholds by a factor of 2-3. When targets and distractors are within 1000 Hz of one another <u>and</u> the they are modulated at different rates, sensitivity to envelope delays can be especially poor, with some subjects requiring 5-8 times larger delays when the distractors are

present than when they are absent.

Manuscripts submitted:

Dye, R.H., Jr., Niemiec, A.J. and Stellmack, M.A. (in review) Discrimination of interaural envelope delays: The effect of randomizing component starting phase. submitted to J. Acoust. Soc. Am.

Psychophysics--Amplitude Moduation Stanley Sheft

The temporal envelope of any sound source represents a fundamental and distinguishing characteristic of the waveform. Recent work has been concerned with the auditory processing of amplitude modulation (AM) as it may relate to sound-source segregation, the identification of the individual sources in a multi-source listening environment. These experiments have investigated both the decision process used by the auditory system to extract the information concerning stimulus modulation, and also the manner and extent to which this information can then be combined across audio-frequency regions. Computer simulations of auditory temporal processing have concentrated on evaluation of possible decision statistics and window durations used to code envelope information along with estimation of the internal noise level of the coding process.

Our previous work using sinusoidal modulators did not indicate the degree of selectivity to modulation parameters needed for accurate sound-source segregation. However, the coherent modulation of most real-world sound sources is irregular, not sinusoidal, characterized by a distinct pattern. Consequently, recent experiments have concentrated on the ability of listeners to process the irregular modulation patterns of narrowband noise. Involvement of envelope coherence in source segregation requires that listeners can both detect the coherence and then in some manner selectively process the various fluctuation patterns that characterize the different sources. Envelope coherence or synchrony detection was therefore evaluated in masking and discrimination conditions requiring selective cross-spectral processing of similar patterns of envelope fluctuation.

If a spectral subset of a complex sound first precedes the sound, the subset will tend to be heard as a separate auditory image when repeated as part of the complex. A cued 2IFC test procedure was used to encourage this type of spectral segregation. In contrast to previous studies of synchrony detection that used a conventional (uncued) procedure, results from the cued procedure indicated relatively small effects of noise bandwidth and of the frequency separation between noise bands. In the masking conditions, the task was to detect coherence among target noise bands in the presence of masker noise bands. Target and masker bands shared a common bandwidth. Though performance was impaired by the maskers, there was less masking than generally observed when modulated maskers are used in experiments evaluating sinusoidal modulation detection, and depth and rate discrimination. In the discrimination conditions, envelope coherence in the nonsignal observation interval also had little effect on performance. The small effects observed

across the various conditions are consistent with the type of selective cross-spectral processing needed for sound-source segregation.

Papers:

Sheft, S. and Yost, W.A. (1990). "Temporal integration in amplitude modulation detection," *J. Acoust. Soc. Am.* **88**, 796-805.

Presentations:

Sheft, S. (1990). "Modeling temporal resolution through repeated observations," Midwestern Acoustical Society, Williams Bay, Wisconsin.

Sheft, S. and Yost, W.A. (1990). "Cued envelope-correlation detection," *J. Acoust. Soc. Am.* Suppl. 1 **88**, S145.

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Auditory Physiology--Temporal Processing William P. Shofner

Neurophysiological experiments during the last year have continued to study how cochlear nucleus neurons encode stimulus information found in the time domain of rippled noises. Information in the time domain can be found in the waveform fine structure and envelope. Rippled noise is a broadband stimulus which produces the perception of pitch, yet is aperiodic in the time domain. Cos+ rippled noise is generated when a broadband noise is delayed and then added to the undelayed noise. The resulting stimulus has a power spectrum that varies in a cosinusoidal fashion in which the peaks are separated by 1/delay. The autocorrelation function of waveform fine structure of cos+ noise has a single peak at the delay of the noise. Thus, unlike wideband noise which is aperiodic and has a flat autocorrelation function, *rippled noise is an aperiodic stimulus that does not have a flat autocorrelation function*. Moreover, the autocorrelation function of the envelope of cos+ noise also has a single peak at the delay. As proposed in last year's progress report, we have made a comparison of the temporal responses of cochlear nucleus neurons in the chinchilla to cos+ and cos- rippled noises. Cos- noise is generated when the delayed version of the noise is subtracted from the undelayed noise; the autocorrelation function of the waveform fine structure of cos- noise shows a null at the delay, while the autocorrelation function of the envelope of cos- noise shows a single peak at the delay.

Neurons which show phase-locking to best frequency tones extract the delay of rippled noise from the waveform fine structure of the stimulus. The neural autocorrelation functions of these neurons show a peak at the delay for cos+ noise and a null at the delay for cos- noise. In contrast, neurons that do not show phase-locking at best frequency do not encode the delay of rippled noise in their temporal discharge patterns. However, a few chopper units (non-

phase-locked) have been found which can extract the delay of the rippled noise from the stimulus envelope. The neural autocorrelation functions of the e neurons show a peak at the delay for both cos+ and cos- noises. Exper r its planned in the coming year will include an evaluation of place-coding mechanisms.

Presentations:

Shofner, W.P. (1990) Temporal responses of cochlear nucleus units in the chinchilla to low frequency tones, tone complexes and rippled noise. Abstr. of the 13th Midwinter Meeting, Assoc. Res. Otolaryngol. p. 400.

Shofner, W.P. (1990) Measurement of the strength of synchrony of chinchilla cochlear nucleus units in response to cos+ noise. Submitted to 1990 Annual Meeting, Society for Neuroscience.

Manuscript submitted:

Shofner, W.P. (in review) Temporal representation of rippled noise in the anteroventral cochlear nucleus of the chinchilla. submitted to J. Acoust. Soc. Am.